THE COMPOSITION OF EXPIRED AIR AND ITS EFFECTS UPON ANIMAL LIFE.

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J. S. BILLINGS, M. D.,
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FROM THE SMITHSONIAN REPORT FOR 1895, PAGES 389-412.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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THE COMPOSITION OF EXPIRED AIR AND ITS EFFECTS UPON ANIMAL LIFE.[1]

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By J. S. BILLINGS, M. D., S. WEIR MITCHELL, M. D., and D. H. BERGEY, M. D.

In May, 1893, a grant was made from the Hodgkins fund to Drs. John S. Billings and S. Weir Mitchell "for the purpose of conducting an investigation into the nature of the peculiar substances of organic origin contained in the air expired by human beings, with special reference to the practical application of the results obtained to problems of ventilation for inhabited rooms."

For a number of years prior to 1888 the prevailing view among physicians and sanitarians had been that the discomfort and dangers to health and life which had been known to exist, sometimes, at least, in unventilated rooms occupied by a number of human beings, were largely or entirely due to peculiar organic matter contained in the air expired by these persons, and that the increase in carbonic acid due to respiration had but little effect in producing these results, its chief importance being that it furnished a convenient means of determining the amount of vitiation of the air. Recently, however, several experimenters have concluded that the organic matters in the exhaled breath are not harmful, at all events to animals, and the main object of the proposed investigation was to determine the correctness of these conclusions.

The effects produced on animals and men by an atmosphere contaminated with their exhalations, and with particulate matters derived from their bodies or their immediate surroundings, may be divided into acute and chronic. The acute effect may be death in a few minutes or hours, as shown by the results observed in the Black Hole of Calcutta, in the steamer *Londonderry*, and in many of the experiments referred to in this report, or it may be simply great discomfort, especially in those unaccustomed to such conditions.

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[1] The full report is printed in Smithsonian Contributions to Knowledge, Vol. XXIX (No. 980), 4to, pp. 81.

The chronic effects include the favoring of the action of certain specific causes of disease commonly known as contagious, if these are present, and perhaps also a general lowering of vitality.

The statistical evidence collected by the English Barrack and Hospital Commission (1)[1] as to the effects of insufficient ventilation upon the health of soldiers in barracks, published in 1861, showed that men who live for a considerable portion of their time in badly ventilated rooms have higher sickness and death rates than have those who occupy well-ventilated rooms, other conditions being the same; and this has also been found to be true with regard to monkeys and other animals. It is evident, however, that in a room occupied by animals or men there are many sources of impurity besides the exhaled breath, and it is still a question whether the expired air contains substances injurious to life, excluding carbonic acid.

The widely divergent results obtained and conclusions reached by different investigators during the last ten years as to whether the exhaled breath of men and animals contains a peculiar volatile organic poison, have made it desirable to repeat and vary such experiments in order, if possible, to settle this important point. The chemical analyses of the air of overcrowded rooms, and the experiments upon animals with various proportions of carbonic acid, made by many investigators, indicate that the evil effects observed are probably not due to the comparatively small proportions of carbonic acid found under such circumstances.

Claude Bernard (2), in 1857, experimented with animals confined in atmospheric air and in mixtures both richer and poorer in oxygen than atmospheric air. A small bird placed in a bell glass of a little more than 2 liters' capacity, containing a mixture of 13 per cent carbonic acid, 39 per cent oxygen, and 48 per cent of nitrogen, died in two and one-half hours. He demonstrated that carbonic acid is not poisonous when injected under the skin of animals—as much as one liter injected under the skin of a rabbit producing no ill effects. No ill effects followed the injection of the gas into the jugular vein and into the carotid artery. An atmosphere of equal parts of oxygen and nitrogen had no effect upon an animal confined in it, while an atmosphere composed of equal parts of carbonic acid and of oxygen produced immediate death in the animal placed in it. He explains the poisonous effects of carbonic acid when respired to be due to the fact that it deprives the animal of oxygen. Similar results were reported by Valentin (3) and by Paul Bert (4).

Richardson, in 1860–61 (5), found that a temperature much higher or lower than 20° C. had the effect of shortening very considerably the lives of animals confined in an unventilated jar, and that these effects were more marked when the animals were confined in an atmosphere

[1] The numbers in parentheses refer to the bibliographical list appended to this report.

richer in oxygen than air, in which case he found that by passing electric sparks from a frictional machine through the fatal air (having previously deprived it of its carbonic acid) it was again made capable of supporting life, from which he concluded that the oxygen is "devitalized" during respiration, and that the electric spark has the faculty of revitalizing it.

Von Pettenkofer, in 1860–1863 (6), showed that the symptoms observed in crowded, ill-ventilated places were not produced by the excess of carbonic acid, nor by a decrease in the proportion of oxygen in the air; neither of these being sufficient in our dwellings, theaters, etc., to produce toxic effects. He did not believe that the impure air of dwellings was directly capable of originating specific diseases, or that it was really a poison in the ordinary sense of the term, but that it diminished the capability of withstanding the influence of disease-producing agencies on the part of those continually breathing such air, and laid down the rule, which has been accepted and taught by sanitarians for thirty-five years, that the proportion of carbonic acid in the atmosphere of inhabited places affords a safe indication as to the amount of the other impurities resulting from respiration and other exhalations from the bodies of the occupants.

Hammond, in 1863 (7), reported experiments in which he sought to remove the carbonic acid and moisture, and to supply fresh air as fast as it is needed to take the place of the carbonic acid removed, thus leaving the "organic matter" to accumulate in the vessel. For this purpose he confined a mouse in a large jar, in which were several sponges saturated with baryta water, by which the carbonic acid was removed as fast as formed. Fresh air was supplied as fast as required by means of a tube communicating with the bell jar and closed by water in the bend of the tube, which acted as a valve. As the air in the bell glass was rarefied by respiration and absorption of the carbonic acid, fresh air flowed in from without, while the arrangement of the tube prevented the air of the bell glass from passing out. The watery vapor exhaled by the animal was absorbed by two or three small pieces of chloride of calcium. The mouse died in forty minutes. The observation was repeated many times, and death ensued invariably in less than an hour. On causing the vitiated air to pass through a solution of permanganate of potash the presence of organic matters in large quantity was demonstrated.

Ransome, in 1870 (8), reported a series of very interesting investigations upon "Organic matter of human breath in health and disease." By condensing the aqueous vapor of the human breath and analyzing it by the Wanklyn and Chapman method, he found that "in ordinary respiration about 0.2 gram of organic matter is given off from a healthy man's lungs in twenty-four hours," while in the air expired by persons affected with certain diseases, he found great variations in the amount of organic matter, the amount being greatest in a case of phthisis complicated with Bright's disease.

Smith (9) employed a lead chamber in his investigations upon the question whether human lungs give off any poisonous agent other than carbonic acid. He found the pulse to fall from 73 to 57 beats per minute, and the number of respirations to rise from 15.5 to 24, as the carbonic acid in the atmosphere increased from 0.04 to 1.73 per cent during four hours. When the proportion of carbonic acid rose to 3 per cent there appeared great weakness of the circulation with slowing of the heart's action, and great difficulty in respiration. He believed that these results should be attributed to other conditions rather than to the excess of carbonic acid, because he found later that it was only when lamps became dim in an atmosphere—indicating a proportion of about 10 per cent of carbonic acid present—that the respiration became difficult.

Seegen and Nowak, in 1879 (10), believed they had demonstrated the presence of poisonous organic matter in the expired breath by passing it over red-hot cupric oxide, but the quantity found was so small that they failed to determine its exact nature and properties.

Hermans, in 1883 (11), was unable to detect any organic matter in the atmosphere of a tin cage in which several persons had been confined for a number of hours, and found that an atmosphere containing from 2 to 4 per cent of carbonic acid and 15 per cent of oxygen was not toxic.

Brown-Séquard and d'Arsonval, in 1887 (12), reported that the air expired by men and dogs in a state of health has the power of producing toxic phenomena, citing three series of experiments on rabbits where such phenomena were observed. In the first series they injected into the vascular system of a rabbit 4 to 6 c. c. of water obtained by injecting from 15 to 25 c. c. of pure filtered water into the trachea of a dog. In a second series from 6 to 7 c. c. of a liquid obtained by condensing the moisture in the exhaled breath of a man were injected into the aorta, or into a vein, of a rabbit. In the third series from 4 to 6 c. c. of a liquid obtained by condensing the moisture in the exhaled breath of a tracheotomized dog were used. The condensed liquid thus obtained was filtered and then injected either into the jugular vein or the carotid artery.

The symptoms observed were dilatation of the pupils, increase of the heart beat to 240, 280, or even 320 per minute, lasting for several days or even weeks. The temperature remained normal, the respiratory movements were generally slowed, and usually there was observed paralysis of the posterior members. Choleraic diarrhea was invariably present. Death usually took place in a few days, or at the farthest in four or five weeks. As a rule, it appeared that larger doses caused labored respiration, violent retching, and contracted pupils. A rapid lowering of temperature, 0.5° to 5° C., was sometimes observed. The appearances that presented post-mortem were much like those observed in cardiac syncope.

They believed they had discovered a volatile organic poison in the exhaled breath and the moisture condensed from it. This poison they

believed to be of the nature of an organic alkaloid, or a ptomaine not unlike Brieger's ptomaine (12[a]).

In further reports, in 1888 (12[b]), they state that none of eleven rabbits in which the condensed pulmonary vapor had been injected into the vascular system in doses of 12 to 30 c. c. survived, but of eight rabbits receiving an injection of from 4 to 8 c. c. three were living after the lapse of from four to five weeks, but were then weak. When the fluid was injected under the skin of the thorax and in the axilla, five out of seven rabbits died rapidly. The results were much the same as when it was injected into the blood. The quantity of the condensed liquid injected in these seven was 20 c. c. in one case, 25 c. c. in three cases, 31 c. c. in one case, 40 c. c. in one case, and 44 c. c. in another case. After death, considerable congestion of the viscera was noted, especially of the lungs. No appearance of embolism was noted. The brain and its membranes were congested, but without visible lesion. The condensed liquid turns concentrated sulphuric acid yellow. The poison is reduced by ammoniacal nitrate of silver solution as well as by chloride of gold. After boiling in a close vessel it is still toxic, showing that the poison is not a microorganism. The boiled lung liquid poisons with more rapidity than that which has not been sterilized, and may kill a pigeon and a guinea pig as well as a rabbit; that it may kill by being injected into the rectum or into the stomach; that a guinea pig two months old was killed within twelve hours by an injection of 3 c. c. into the peritoneal cavity. If injected into the lungs this liquid produces rapid congestion followed by true inflammation and red hepatization.

In an experiment with two dogs it was arranged that one breathed ordinary air and the second inhaled air which came from the lungs of the other. The dogs were of the same weight, 15 kilograms. The experiment continued for six hours and forty minutes. No appreciable or immediate consecutive accidents were produced.

In a second experiment the pulmonary liquid was collected from dogs through a tracheotomy tube, to exclude impurities furnished by the mouth. The air inhaled was first washed to remove dust. The moisture in the air expired was condensed, and the liquid collected in a flask surrounded by ice. At the moment of injection this liquid was filtered, and was then injected at the temperature of the laboratory, about 12° C. If the animal was kept immovable from twelve to sixteen hours, inflammation of the air passages was produced. The liquid of the first hours came from a thoroughly sound lung, and in the later hours from a diseased lung. The two were collected separately and tried separately. For 1 kilogram of the animal, for each hour, the mean quantity of fluid obtained was 0.38 gram, varying from 0.28 to 0.48 gram. It was greater in the beginning and lessened the longer the animal was kept in a fixed position. It was injected into the marginal vein of the ear of a rabbit by means of a syringe, 75 c. c. being injected. When the

injection did not exceed 40 to 50 c. c. the time occupied by the injection was from six to fifteen minutes. Experiments made by injections upon the dog were negative without exception. Experiments made upon the rabbit produced lesions, but the relation between these and the injections is uncertain.

Dastre and Loye, in 1888 (13), reported that they had exposed one dog to the expired breath of another for six hours without noting any effects. They inoculated animals with the condensed moisture of respiration, as follows:

Animals.	Quantity of fluid.	Results.
	Cubic centimeters.	
Five rabbits (each)	33 to 75	Negative.
Two guinea pigs (each)	5 to 7	Do.
Two dogs (each)	30 to 53	Do.
Two frogs (each)	2 to 3	Do.
Two rabbits (each)	50 to 190	Died.
A young dog (each)	*a* 30	Do.

a Of water.

They found that 50 to 70 c. c. of the condensed fluid of respiration (20 to 35 c. c. per kilogram) could be injected into the veins of the ear of a dog without producing any of the symptoms reported by Brown-Séquard and d'Arsonval. They observed one death during the injection of 190 c. c. (60 c. c. per kilogram), yet by control experiments with water they obtained a more remarkable result—a rapid death from the injection of 30 c. c. of distilled water (25 c. c. per kilogram).

Russo-Giliberti and Alessi, in 1888 (14), reported experiments confirming the results obtained by Dastre and Loye.

Brown-Séquard and d'Arsonval, in 1889 (15), reported a new form of experiment, by means of which they obtained additional evidence in support of their former statements. The new form of experiment consisted in confining animals (rabbits) in a series of metallic cages connected by means of rubber tubing, through which a constant current of air is aspirated. The animal in the last cage of the series receives air that has traversed the entire series of cages, and is loaded with the impurities from the lungs of the animals in the other cages. This animal succumbs, after a time, to the atmospheric conditions present. After another interval of some hours the animal in the next to the last cage also dies, the first and second animals usually remaining alive. They could not attribute the death of these animals to excess of carbonic acid in the atmosphere of the cages, because they rarely found more than 3 per cent of this gas in the last jar with small animals, or 6 per cent with larger animals. On placing absorption tubes containing concentrated H_2SO_4 between the last two cages, the animal in the last cage remained alive, while that in the cage before it was the first to die. They concluded from these facts that the death of the animals

was produced by a volatile poison, which poison is absorbed by the H_2SO_4, which thus saves the life of the animal in the last cage.

They stated (16) that any alkali used to absorb carbonic acid from expired air would also change the organic poison, and proposed an apparatus by means of which the organic poison should be supplied to the fresh air entering the jars by volatilizing it from fluid condensed from the expired air.

V. Hofmann-Wellenhof, in 1888 (17), found that when he injected large quantities of the condensed fluid of respiration at 12° C., instead of at 37° C.—intravenous injection—a resemblance of the results obtained by Brown-Séquard and d'Arsonval was produced. Under such circumstances he observed muscle weakness, slowing of respiration, fall of temperature, and dilatation of the pupils, though the animals remained alive. He injected ten rabbits with 6 to 30 c. c. of the fluid warmed to the body temperature, all the results being negative. Three other animals were injected in the jugular vein, one receiving 28 c. c. of the fluid, another 25 c. c. of distilled water, and a third 50 c. c. of distilled water. There was no difference in the symptoms noted in the animals. He noticed symptoms of depression only after injecting 50 c. c., or more, of the fluid. In a series of seventeen experiments with inoculations of from 30 to 50 c. c. each of the fluid, in twelve there appeared hæmoglobinuria; six of these died. As the result of his experiments, he concluded that the existence of a volatile poison in the expired air of healthy human beings has not been demonstrated by his experiments, this being a direct contradiction of the results of Brown-Séquard and d'Arsonval, as were also those of Dastre and Loye.

Uffelmann, in 1888 (18), found that there was a perceptible increase in organic matter in the atmosphere of a sleeping room occupied by several persons for some hours, increasing in amount with the length of time the room was occupied.

Lehmann and Jessen, in 1890 (19), collected 15 to 20 c. c. of the condensed fluid per hour exhaled from the breath of a person breathing through a glass spiral laid in ice. The fluid was always clear as water, odorless, and of neutral reaction. Nessler's reagent showed the presence of ammonia constantly, with good teeth but little, sometimes merely a trace, with bad teeth, more, though never more than 10 milligrams of NH_4Cl in 1 liter. Traces of HCl were also constantly found. A small sediment remained on evaporation, ranging from 39 to 86.4 milligrams per liter of fluid. This they believed to originate from the glass vessel; probably calcium oxalate. They tested its reducing power upon solution of permanganate of potash, making two control determinations. The first determination showed 3.6 milligrams of O for the oxidation of 1 L.; the second, 4.2 milligrams of O. They were unable to obtain any alkaloid reaction in the condensed fluid, or in its distillates, by means of $PtCl_4$, $AuCl_3$, KCdI, KBiI, KI, Bouchardet's reagent, K_2CrO_6, picric

acid, metawolframic acid, or phosphowolframic acid. Only sublimate gave at times an opalescence which, like the yellow coloration of the Nessler reagent, pointed to traces of NH_3. Neither could they succeed, according to the method of Würtz, in obtaining a lime or oxalic acid-free filtrate. The ammoniacal silver solution, according to Brown-Séquard and d'Arsonval's method, failed to give the desired reaction, remaining clear. They confined a man, clothed in his working clothes, in a zinc cage for about one-half an hour, then allowed a boy and girl to inhale the air from the cage. No ill effects, except increase of respirations to 30 and 40 per minute, were noticeable. They had complete negative results from inoculations of condensed fluid into animals.

Lipari and Crisafulli, in 1889–90 (20), reported results which were in accord with those of Dastre and Loye and directly opposed to those of Brown-Séquard and d'Arsonval. They could find no organic principle possessing toxic properties in the expired breath of healthy persons.

Margouty, in 1891 (21), reported the results of experiments similar to those of Hammond, and also of experiments in injecting fluid condensed from expired air into animals. His results did not correspond to those reported by Hammond, and there was no evidence of toxic properties in the injected fluids.

Haldane and Smith, in 1892 (22), published an account of experiments in which an air-tight chamber, 6 feet 2 inches high, 2 feet 11 inches wide, and 3 feet 11 inches long, was employed. Samples of air for analysis were drawn off through a tube placed in the wall of the chamber, about 3 feet from the floor. When one person remained in this chamber until the vitiation was from ten to twenty times as great as in the most crowded and worst ventilated public buildings, there was no perceptible odor or sense of oppression. Air vitiated to such an extent as to completely prevent a match from burning had no appreciable effect upon the subject of the experiment. In other experiments hyperpnœa and other phenomena produced were apparently due to the increased proportion of carbonic acid.

With rabbits weighing 1,800 grams, hematuria was produced when the amount of boiled distilled water injected passed beyond 100 c. c., and therefore 80 c. c. were taken as the maximum dose.

To obtain the condensed liquid from the lungs, a man expired through a Liebig condenser, in the jacket of which was flowing a stream of ice-cold water. The condensation liquid was collected in a flask, the bulb of which was buried in ice; and when the required amount (80 c. c.) had been obtained, it was at once injected into the subcutaneous tissue of the back. Six rabbits were thus injected, each with 80 c. c. of the fluid, with no evident disturbance of health in any of them; 80 c. c. to a rabbit corresponds to a dose of about 3 liters to a man. They also repeated the experiments of Brown-Séquard and d'Arsonval in supplying to the animals air charged with organic matter drawn directly from the lungs of other animals. Two large rabbits

were placed in an air-tight chamber and a current of air drawn through this was supplied to two young rabbits under observation; no effect was produced.

Merkel, in 1892 (23), reported an experiment in which four air-tight glass vessels, of 1½ liters' capacity, were connected by means of glass tubes, a mouse being placed in each vessel. Between the third and fourth vessels a Geissler absorption tube containing sulphuric acid was interposed. Air was now drawn slowly through the vessels by means of an aspirator, so that the second mouse breathed the air from the first, the third from that of the second, etc. The result was, just as in the experiment of Brown-Séquard and d'Arsonval, that the mouse in the third vessel died first, after sixteen to twenty hours, while that in the fourth vessel remained alive.

The conclusion is drawn that, as the fourth mouse remained alive, the death of the third can not have been due to excess of carbonic acid, or deficiency of oxygen in the air, but must have been caused by the presence of some volatile substance which is absorbed or destroyed by sulphuric acid.

The symptoms presented by the mice before death were at first restlessness and gradually increasing acceleration of respiration, afterwards slowing of respiration, and finally spasmodic, deep respirations, becoming constantly less frequent until the advent of death. The proportion of carbonic acid in the air led through the glass vessels was not poisonous; it amounted in the highest case to 1.5 per cent.

He concludes that the expired breath of healthy persons contains a volatile poison in extremely small quantities, being probably a base which is poisonous in its gaseous state, but loses its toxicity after combination with acids. His belief in the toxicity of the organic matter contained in the expired breath of human beings is based solely upon the results he obtained in the Brown-Séquard and d'Arsonval experiment.

Haldane and Smith, in 1893 (24), repeated the Brown-Séquard experiment, using five bottles, each of a capacity of 1 to 1½ liters, connected by means of tubes. A mouse was placed in each bottle, and ventilation established through the whole system by means of a filter pump, a small gas-meter being placed between the last bottle and the pump. Specimens of air leaving the last bottle were drawn off at intervals for analysis. Full-grown mice were used. The mice in the last two bottles were exposed to the full effect of the vitiated air for fifty-three hours without detriment.

In a second experiment an absorption tube containing pumice stone saturated with sulphuric acid was placed between the last two bottles. This experiment was continued for thirty hours; no serious effects were observed. The amount of ventilation furnished was from 15 to 24 liters per hour. The mice remained normal after having been in the bottle three days, and the percentage of carbonic acid in the last bottle had varied from 2.4 to 5.2, averaging about 3 per cent.

They state that these experiments, like their former ones on rabbits and man, are distinctly against the theory that a volatile poison other than carbonic acid exists in the expired air.

Beu, in 1893 (25), reported the results of experiments, made under the direction of Uffelmann, in which the condensed moisture of expired air was collected by the methods usually employed, taking the precaution to cleanse his apparatus with solution of $KMnO_4$ and distilled water, and likewise sterilizing the apparatus before it was brought into use. The saliva is collected in a Woulff bottle attached before the condenser. The amount of air expired, measured by a gas meter, was found to be 3,000 liters in eight hours, from which he collected 100 c. c. of fluid. A distinct ammonia reaction was obtained upon the addition of Nessler's reagent. Nitrate of silver failed to show the presence of chlorine.

Its reducing power upon solution of permanganate of potash showed 50 milligrams of oxygen necessary to oxidize 1 liter of fluid, or 15 milligrams in twenty-four hours, which denotes 0.0017 milligrams per liter of expired air. The alkaloid reaction with $AuCl_3$, KI, phosphomolybdate of potash, gave negative results.

He expired 500 liters through 150 c. c. of a 1 per cent solution of HCl, then evaporating to dryness on the water bath. A yellowish-brown deposit remained. This deposit, dissolved in distilled water, formed a fatty layer on the surface of the slightly yellow fluid. The whole quantity, 1.5 grams, was warmed to the body temperature and injected under the skin of the back of a white mouse without producing observable symptoms. This fluid had a distinct odor not comparable to anything.

He next confined a mouse in a sealed glass vessel, having a globe attached, with potash solution to absorb the carbonic acid: 3,200 expirations of air were conducted into the glass vessel during the three hours; no effect noticeable. In a second experiment the carbonic acid was not absorbed, the experiment lasting four hours: no effect.

He repeated the Brown-Séquard experiment, using white mice in four glass cages. The death of the animals, he believes, was due to changes in the temperature and the accumulation of moisture in the jars. He believes the protection afforded by H_2SO_4 in Brown-Séquard and d'Arsonval's experiments was due to its abstraction of the moisture from the air. An acute poisoning through the organic matters contained in the expired air he believes to be impossible, at least as not shown by anything in his experiments.

Rauer, in 1893 (26), used white mice confined in glass vessels of about 1½ liters' capacity, the bottom of which was covered with oats. The cork was perforated by three tubes. One of these passed down near the bottom of the vessel and served for the entrance of air; the second terminated just below the cork and served for the exit of air, and the third extended down to about the height of the animal, but

was usually closed: this was only used for the removal of air for its chemical examination. In the beginning thermometers and hygrometers were used in the vessels, but they were found to be unimportant and were abandoned. The whole apparatus was connected with a large aspirator.

In an experiment with five animals and a ventilation of 4 liters per hour, the carbonic acid was found to amount to 9.3 per cent after five hours. In another experiment with six animals and with a ventilation of 2½ liters per hour, he inserted four absorption tubes, with soda lime between the last two jars, and a Geissler tube containing concentrated H_2SO_4 between the fourth and fifth. The sixth animal remained alive, while the fifth died earlier than the fifth animal in the first experiment. He concludes that there is no organic poison in expired air, death being due to the excess of carbonic acid in the atmospheres of the jars.

Sanfelice, in 1893 (27), reported that he had repeated the Hammond experiment, using a flask of about 5 liters' capacity, the animal dying in six or seven hours. He is undecided as to the existence of a volatile expiratory poison, though he thinks that other factors, for instance, heat radiation, have an important influence upon the results.

Lübbert and Peters, in 1894 (28), reported that they had repeated the Brown-Séquard experiment, placing a guinea pig in each of a series of four flasks. Between the third and fourth flasks they placed a combustion tube through which the air coming from the third flask was conducted, passing over red-hot cupric oxide, to remove the organic matter. Before reaching the fourth flask, the air was again cooled by conducting it through a cylinder surrounded with ice. In this manner all moisture contained in the air was condensed. From this cylinder the air passes through a series of twelve U-tubes, each made from a piece of tubing 80 centimeters in length and of 2 millimeters internal diameter. During its passage through these U-tubes the air assumed a temperature of about 18° C. as it entered the fourth flask. The results obtained by this arrangement substantiated the conclusions they had formed from conducting the experiment in the ordinary manner, that the cause of death was traceable to the high per cent of carbonic acid. The removal of the organic matter by combustion failed to save the life of the animal in the last jar when the carbonic acid had increased to 11 or 12 per cent. After the absorption of the carbonic acid by means of soda lime the last animal remained alive. They conclude, therefore, that the poisonous expiratory poison of Brown-Séquard and d'Arsonval does not exist, but that death is produced by the excess of carbonic acid in the flasks.

Brown-Séquard and d'Arsonval, in 1894 (29), reported further experiments, and at the same time gave fuller details as to all their experiments and the apparatus employed. They had inoculated over 100 animals with the condensed fluid of respiration and believed in the truth of their former statements as firmly as ever. They could not

understand the failures on the part of the other experimenters. They emphatically reaffirm that the expired breath of man and animals contains a volatile organic poison producing the results reported by them, and that these results are not produced by excess of carbonic acid or deficiency of oxygen in the air.

From the foregoing summary of the reports of different experimenters, it will be seen that widely different results have been reported by them, but that the majority of the later investigators agree in denying that the exhaled breath of healthy human beings or of animals contains a poisonous organic alkaloid, or any poisonous product other than carbonic acid, yet in any case positive results require an explanation which shall account for the facts.

DR. BERGEY'S EXPERIMENTS.

The first experiments made by Dr. Bergey were to ascertain whether the condensed moisture of air expired by man in ordinary, quiet respiration contains any particulate organic matters, such as microorganisms, epithelial scales, etc. The test for microorganisms was made by having an adult man expire for from twenty to thirty minutes through sterilized melted gelatin, which was then preserved as a culture for from twenty to thirty days. In the first trial, six, and in the second, two colonies of common air organisms developed; but when special care was taken to thoroughly sterilize the vessels used, the result was that in two consecutive trials the gelatin remained sterile. Epithelial scales and other particulate matters were sought for by condensing the vapor of the exhaled breath and examining the product with the microscope, with and without the use of stains. In six preparations thus examined no bacteria or epithelial cells were found. This result was to be expected, since neither bacteria nor wetted particles pass into the air from the surface of fluids, or from moist surfaces, unless the air currents are sufficiently powerful to take up particles of the liquid itself in the form of spray.

Abbott (30), in his paper on sewer gas, reports some experiments made to determine the possibility of conveying microorganisms from liquid culture media by means of a current of air bubbling through such media; also by means of ordinary baker's yeast inoculated into media containing from 4 to 5 per cent of glucose. No bacteria were carried from the culture by the exploding air bubbles produced by the yeast, but a current of air equal to 3½ liters in six hours, bubbling through a liquid culture, carried with it some of the organisms in the culture.

The determinations of ammonia in the condensed fluid of expired air, the estimation of its reducing power upon solution of permanganate of potash, and its reaction with various reagents, were made with fluids collected from a healthy man, from a man with a tracheal fistula following excision of the larynx, the expired air not coming in contact with the mouth or the pharynx, and from a man suffering from well-marked

tuberculosis of the lungs. In each case the amount of ammonia and of albuminoid ammonia in the fluid was very small, the average being, in grams per liter of fluid:

	Free ammonia.	Albuminoid ammonia.
Healthy man	0.019	0.081
Man with tracheal fistula	.00046	.00036
Consumptive	.003	.0034

The oxidizable matter in these fluids, as shown by their reducing power on a solution of permanganate of potash, was determined. The average results, stated in milligrams of oxygen consumed per liter of condensed fluid, are as follows: Healthy man, 10.72; man with tracheal fistula, 13.49; consumptive, 19.34. The high average for the man with the tracheal fistula is due to a single observation, for which the figure was 24.916. Omitting this, the average for the three other observations would be 9.68.

The average for five specimens of fluid condensed from the expired air of a healthy man four hours after he had taken a meal was 11.98, while the average for six specimens from the breath of the same man half an hour after the meal was only 3.86. For two specimens from the same man collected three and a half and four hours after a meal, but just after the mouth had been thoroughly rinsed with warm water, the average was 2.49. These results indicate that the ammonia and oxidizable organic matter in the condensed fluid were, to a large extent, due to products of decomposition of organic matters in the mouth. The well-known fact that the amount of oxygen absorbed and of carbonic acid given off varies according to whether the person is fasting or has recently taken a meal, may possibly be in part due to the same cause, but the results obtained by Birkholz (31) indicate that it can only be in part. Ransome (8) reports no marked difference in the amount of ammonia, or of oxidizable organic matter, as determined by the permanganate test, contained in the fluids collected from the exhaled breath soon after a meal and in that collected from a fasting person. Beu (25) found a much higher proportion of oxidizable matter in the fluid condensed from his own breath (50 milligrams of oxygen required per liter of fluid) than was found in Dr. Bergey's experiments. His results indicated the exhalation of 15 milligrams of organic matter in twenty-four hours, the corresponding figure from Ransome's results being 20 milligrams. About 12 c. c. of fluid was collected from about 335 liters of air expired per hour, being nearly equal to the results obtained by Beu (25), who condensed 100 c. c. of the fluid from 3 cubic meters of air expired in eight hours.

Renk (32, p. 162) gives a table showing that in an average quantity of 9,000 liters of air expired in a day by a healthy man, the amount of moisture may be from 200 to 400 grams, depending on the temperature

and relative humidity of the inspired air. With air containing 50 per cent of moisture inspired at 25° C., the amount of moisture is 293 grams, or about the result given by Beu, referred to above.

Lehmann and Jessen (19) found that between 3 and 4 milligrams of oxygen were required in 1 liter of fluid to effect oxidation, and note that more ammonia was present in the fluid collected from a person with decayed teeth than in that obtained from a person whose teeth were sound. The very considerable differences in the amounts of ammonia and of oxidizable matter found in the fluid condensed from expired air by different experimenters, and by the same experimenter, in fluids obtained from the same person at different times, are probably due to several different causes and their combinations. The amount of fluid condensed per liter of expired air varies from 0.003 to 0.004 c. c. The soundness and cleanliness of the mouth and teeth influence the amount of ammonia and oxidizable matter expired. Variations in the amount of organic matter contained in the inhaled air may possibly influence the result, but this influence must be slight. Ransome's results indicate that the age, health, and vigor of the person may affect the amount of organic matter exhaled, and Dr. Bergey's experiments with the fluid obtained from the consumptive patient show that a smaller proportion of ammonia and a larger amount of oxidizable matter were present in it than in the fluid collected from a healthy man. It should be remembered, also, that it is extremely difficult to obtain accurate results in quantitative determinations of such very minute amounts of ammonia and oxidizable matters as are found in expired air, and a part of the differences in results obtained is no doubt due to unnoted differences in the details of the experiment.

The results of tests for the presence of an organic alkaloid in the condensed fluids obtained by Dr. Bergey were negative, corresponding to those reported by Lehmann and Jessen (19) and by Beu (25).

The results of attempts to condense the moisture of the air in the hospital ward were not satisfactory, and the determinations of ammonia in the fluid obtained are not comparable, except they show that the placing of a dust filter in front of the condensing apparatus causes a marked reduction in the proportion of ammonia in the condensed fluid. The evaporation equaled the condensation except on days when the external air was saturated with moisture, hence no moisture was collected on clear days, but on such days some dust particles may have accumulated in the apparatus which had no filter.

Several series of experiments were made to determine the nature of the gaseous mixtures in which small animals die with symptoms of asphyxia. The first of these series were repetitions of the experiments reported by Hammond and described above. Mice and sparrows were used. It was found impossible, by Hammond's method, to absorb all the carbonic acid produced by an animal. At the time of death of the sparrows, the carbonic acid had increased until it formed from 12.27

to 14.08, or an average for eight experiments of 13.24 per cent of the air, while the oxygen had diminished to from 3.25 to 5.61, or an average of 4.67 per cent of the air. The symptoms observed were those produced by insufficiency of oxygen, and there was no evidence that death was due to organic matters in the air. The duration of life in the animals confined was from three to six hours, being much longer than that reported by Hammond, using a slightly smaller vessel, viz. less than one hour, and corresponds to the results reported by Sanfelice (33), who found that the animals lived from six to seven hours. When the experiment was so modified that all the carbonic acid was removed from the air breathed by the animal, the animal did not die in seven hours, although the percentage of oxygen had been reduced to 18.35. These experiments, therefore, furnish no evidence of the existence of an organic poison in the expired air, but the method of absorbing carbonic acid by an alkali is said by Brown-Séquard and d'Arsonval (16) to change the organic poison which they claim to be present, and hence these experiments are not conclusive on this point.

A series of experiments was also made upon mice and sparrows to determine the time required to produce death by asphyxia when the animal is confined in a jar of known capacity, when no provision is made for removing carbonic acid and moisture, or for supplying fresh air, and also to determine the proportions of carbonic acid and of oxygen existing in the inclosed air at the time of death. In connection with these experiments, it was also sought to determine the influence which high or low temperatures of the air would have on the result.

A mouse weighing 21 grams, placed in a jar of 1,000 c. c. capacity at a temperature of 30° C., lived four hours; in a jar of 2,000 c. c. capacity a similar mouse lived seven and a half hours; in one case when the room temperature was 25.5° C., in another case when the room temperature was 5° C. In the first case, death occurred when the amount of carbonic acid was 12 and that of the oxygen 8.6 per cent of the mixture; in the second case, the proportions were 13.2 per cent of carbonic acid and 6.4 per cent of oxygen; and in the third case, 10 per cent of carbonic acid and 9.2 per cent of oxygen. There are considerable differences in susceptibility to the effects of an impure atmosphere in individual mice, but when a mouse is placed in a closed jar containing ordinary atmospheric air, the time required to produce death is usually that required to produce the proportions of carbonic acid and of oxygen indicated above, and, hence, is in proportion to the size of the jar. A mouse should live about twice as long in a jar of 2,000 c. c. as in one of 1,000 c. c., other conditions as to temperature, etc., being the same, and commencing with ordinary atmospheric air.

The duration of life in the experiments with atmospheric air in closed vessels, making due allowance for variations in the air volume, coincides quite closely with the duration of life in the Hammond experiment. The air analyses at death of the animals in the two forms of

experiment, also gave very similar results. In comparing the results it is necessary to bear in mind the differences in the size of the jars and in the weight of the animals used in the several experiments. As a general rule, the animal dies when the carbonic acid has increased to between 12 and 13 per cent and the oxygen has diminished to between 5 and 6 per cent. Is death due to the increase in the carbonic acid, or to the diminution in the oxygen, or to both?

Some data for answering this question are presented, showing the results obtained by placing animals in gaseous mixtures containing various proportions of carbonic acid, oxygen, and nitrogen. The animals experimented on were mice, rats, rabbits, guinea pigs, and sparrows. The diminution in oxygen in the inspired air was the most important factor in producing death, and so long as the oxygen is present in the proportion of 6 per cent and upward, carbonic acid may be present to the amount of 20 per cent without causing death. When the carbonic acid forms much more than 20 per cent of the mixture, say 30 to 40 per cent, the oxygen must form at least 12 per cent to preserve life.

If the proportion of oxygen in the mixture be reduced, the duration of life is shortened, as will be seen from the following table:

No.	Weight.	At beginning of experiment.			At end of experiment.			Duration of life.	Capacity of jar.
		CO.	O.	N.	CO.	O.	N.		
	Grams.	*Per cent*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Hours.*	*c. c.*
8	18	0	11.35	88.65	6.56	4.14	89.3	3½	2,280
9	15	0	11 35	88.65	7.43	3.58	89	4⅛	2,280
10	17	0	11.35	88.65	7.52	3.16	89.2	4⅛	2,280

In these experiments, the proportion of oxygen was reduced to about one-half of that in the normal atmosphere, and the duration of life was also reduced about one-half.

The toleration which is acquired by an animal by prolonged sojourn in an atmosphere which is gradually becoming richer in carbonic acid and poorer in oxygen, makes it impossible to compare the results as to duration of life in such experiments with the results of experiments in which the animal is placed at once in an atmosphere containing abnormal proportions of these gases, so far as the effects of increase of carbonic acid and diminution of oxygen are concerned, but death does not occur in atmospheres in which the carbonic acid does not exceed 10 per cent unless the oxygen is reduced to below 7 per cent of the mixture.

A series of experiments was made by injecting into animals the fluid condensed from the air expired by healthy persons and by a man with a tracheal fistula, from whom it was possible to obtain such fluid without contamination from the exhalations from the mouth. The injections

were made into the general circulation in rabbits, and into the peritoneal cavities of rabbits, guinea pigs, and white rats, following the methods employed by Brown-Séquard and d'Arsonval and by V. Hofmann-Wellenhof. The fluid was collected with the greatest care in a sterilized apparatus; subsequent cultures made from it indicating that it was sterile. It was warmed to about 35° C. before injection. The proportion injected, as compared with the body weight of the animals, was, in some instances, less than that used by Brown-Séquard and d'Arsonval, in others greater than the smallest quantities used by them with fatal effects.

In most of the animals no observable disturbance of health was produced, nor did this condition alter in the course of several months during which they were kept under observation. One rabbit died thirty-two days after having received an injection into its peritoneal cavity of 5 c. c. of fluid condensed from the breath of a man with tracheal fistula. The results of post-mortem examination showed focal necrosis in the liver, but no ecchymoses and hemorrhages in the lungs and intestines, such as are reported as a characteristic result of such injections by Brown-Séquard and d'Arsonval. Three other rabbits which had received injections of the condensed fluid, and had remained apparently perfectly well from six weeks to seven months, were killed and careful post-mortem examinations made. The results of these examinations showed that there was no special disease or degeneration in the organs of these animals.

The results of this series of experiments are, therefore, in accord with those reported by V. Hofmann-Wellenhof, and indicate that fluid condensed from the pulmonary exhalations of man has no toxic or specially injurious effect when injected into animals, and that there is no evidence that such fluid contains an organic poison.

The attempt to collect condensed moisture from the air of the hospital ward was but partially successful, as has been stated above, and a sufficient amount of the fluid to make injection experiments was not directly obtained. To overcome this difficulty, the air of the ward was drawn over sterilized glycerin, which was then diluted with distilled water, and the product injected into animals. Three of the animals thus injected died between four and six weeks later, but the post-mortem examinations failed to show any clear connection between the injection and the fatal result. As it was shown that the fluid collected and that the dust in the ward contained several species of bacteria, including pathogenic forms, it was to be expected that more definite results would have been obtained, but the power of the cells and tissues to resist the pathogenic organisms was sufficient to prevent their action in each case, except, perhaps, in one, in which the abscess produced may have been due to pyogenic bacteria in the injected fluid.

A number of experiments were made in which animals, in a series of bell jars, were caused to breathe air which became more contaminated

with the products of respiration as it passed through the series, being a repetition of the experiments of Brown-Séquard and d'Arsonval.

In the great majority of cases, death was evidently due to the diminution in the oxygen and increase in the carbonic acid, the proportions of these gases present in the jar when an animal died being that as reported, i. e., the oxygen was reduced to between 4 and 6 per cent and the carbonic acid increased to from 12 to 14 per cent. The mode of death of the animals was similar to that observed in slow asphyxia, and the results of careful post-mortem examination and microscopic investigation do not indicate the effects of any organic poison.

The insertion of absorption tubes containing caustic alkalies between the bell jars, to absorb the carbonic acid, and of concentrated sulphuric acid, did not give results corresponding to those reported by Brown-Séquard and d'Arsonval.

The mice became habituated, to a certain extent at least, to the conditions under which they were placed, and could live in an atmosphere which was almost immediately fatal to a fresh mouse placed in it. This had already been demonstrated by Bernard. In the case of several mice, this power to resist the foul atmosphere was preserved for from three to eight days after they had been removed from the jar, so that they had a certain degree of permanent immunity. Experiments were made to see if it was possible to develop such an immunity, and the results obtained indicate such a possibility, but further investigation will be necessary to settle this important point. At present it is uncertain to what extent the immunity observed in a few mice was possessed by them before they were experimented on, or was produced by their first exposures to the vitiated atmospheres.

From the data accumulated with reference to the composition of the atmosphere in these bell jars by repeated analyses at short intervals, compared with the results reported by Brown-Séquard and d'Arsonval, it seems probable that the cases in which the last animal in the series survived some of the others, and a low percentage of carbonic acid was found in the jar, should be attributed entirely to defects either in methods of air analyses or in the apparatus, or in both. If, however, the life of the last animal was apparently saved by H_2SO_4 in Dr. Bergey's experiments, it was due to leakage in the connections from the increased resistance caused by the interposition of the absorption tube. This is an important fact, which is in direct opposition to the theory of Brown-Séquard and d'Arsonval with regard to the influence of the H_2SO_4 in the absorption tubes. The great differences in individual susceptibility of different animals must also be taken into account in considering the results of these experiments. In some mice there seems to be a very considerable immunity against the asphyxiating effect of an atmosphere poor in oxygen and rich in carbonic acid.

The duration of life of individual animals in experiments of this kind depends upon the size of the bell jars in relation to the size of the

animal, on the amount of fresh air supplied, on conditions of temperature and moisture, and on individual peculiarities of the animal; and it seems probable that variations in these factors will account for the different results obtained by different experimenters. The symptoms in the animals which died were those of death by slow asphyxia.

Microscopic examination of the organs presented a picture coinciding with the gross post-mortem appearances. In the lungs the capillaries were found to be distended with blood, occluding in many cases the lumen of the alveoli and air cells, and presenting a typical picture of passive hyperæmia. In the liver, kidneys, and spleen, as well as in the intestines, the capillaries were likewise overloaded with blood. Pathological changes were but rarely noted, and some of these, such as slight proliferation of connective-tissue elements between the tubules of the kidney, and in rarer instances, in the interlobular spaces of the liver, are such as are occasionally found in animals which have not been subjected to such conditions, and may, therefore, have existed in the animals at the beginning of the experiment. All the changes which were constantly present may properly be attributed to the action of the carbonic acid and the low percentage of oxygen in the atmosphere, interfering with the circulation and aeration of the blood. The lesions reported by Brown-Séquard and d'Arsonval as characteristic in such cases were not seen. No focal necroses or peculiar uniform degenerative changes were found. The results of these experiments, therefore, do not agree with those reported by Brown-Séquard and d'Arsonval—and furnish no evidence of the existence of an organic poison in the air expired by animals.

CONCLUSIONS.

1. The results obtained in this research indicate that in air expired by healthy mice, sparrows, rabbits, guinea pigs, or men, there is no peculiar organic matter which is poisonous to the animals mentioned (excluding man), or which tends to produce in these animals any special form of disease. The injurious effects of such air observed appeared to be due entirely to the diminution of oxygen, or the increase of carbonic acid, or to a combination of these two factors. They also make it very improbable that the minute quantity of organic matter contained in the air expired from human lungs has any deleterious influence upon men who inhale it in ordinary rooms, and, hence, it is probably unnecessary to take this factor into account in providing for the ventilation of such rooms.

2. In ordinary, quiet respiration, no bacteria, epithelial scales, or particles of dead tissue are contained in the expired air. In the act of coughing or sneezing, such organisms or particles may probably be thrown out.

3. The minute quantity of ammonia, or of combined nitrogen, or other oxidizable matters, found in the condensed moisture of human breath appears to be largely due to products of the decomposition of

organic matter which is constantly going on in the mouth and pharynx. This is shown by the effects of cleansing the mouth and teeth upon the amount of such matters in the condensed moisture of the breath and also by the differences in this respect between the air exhaled through a tracheal fistula and that expired in the usual way.

4. The air in an inhabited room, such as the hospital ward in which experiments were made, is contaminated from many sources besides the expired air of the occupants, and the most important of these contaminations are in the form of minute particles or dusts. The experiments on the air of the hospital ward and with the moisture condensed therefrom show that the greater part of the ammonia in the air was probably connected with dust particles which could be removed by a filter. They also showed that in this dust there were microorganisms, including some of the bacteria which produce inflammation and suppuration, and it is probable that these were the only really dangerous elements in this air.

5. The experiments in which animals were compelled to breathe air vitiated by the products of either their own respiration or by those of other animals, or were injected with fluid condensed from expired air, gave results contrary to those reported by Hammond, by Brown-Séquard and d'Arsonval, and by Merkel, but corresponding to those reported by Dastre and Loye, Russo-Giliberti and Alessi, Hofmann-Wellenhof, Rauer, and other experimenters referred to in the preliminary historical sketch of this report, and make it improbable that there is any peculiar volatile poisonous matter in the air expired by healthy men and animals other than carbonic acid. It must be borne in mind, however, that the results of such experiments upon animals as are referred to in this report may be applicable only in part to human beings. It does not necessarily follow that a man would not be injured by continually living in an atmosphere containing 2 parts per 1,000 of carbonic acid and other products of respiration, of cutaneous excretion, and of putrefactive decomposition of organic matters, because it is found that a mouse, a guinea pig, or a rabbit seems to suffer no ill effects from living under such conditions for several days, weeks, or months, but it does follow that the evidence which has heretofore been supposed to demonstrate the evil effects of bad ventilation upon human health should be carefully scrutinized.

6. The effects of reduction of oxygen and increase of carbonic acid to a certain degree appear to be the same in artificial mixtures of these gases as in air in which the change of proportion of these gases has been produced by respiration.

7. The effect of habit, which may enable an animal to live in an atmosphere in which, by gradual change, the proportion of oxygen has become so low and that of the carbonic acid so high that a similar animal brought from fresh air into it dies almost immediately, has been observed before, but we are not aware that a continuance of this

immunity produced by it had been previously noted. The experiments show that such an immunity may either exist normally or be produced in certain mice, but that these cases are very exceptional, and it is very desirable that a special research should be made to determine, if possible, the conditions upon which such a continuance of immunity depends.

8. An excessively high or low temperature has a decided effect upon the production of asphyxia by diminution of oxygen and increase of carbonic acid. At high temperatures the respiratory centers are affected, where evaporation from the skin and mucous surfaces is checked by the air being saturated with moisture; at low temperatures the consumption of oxygen increases, and the demand for it becomes more urgent.

So far as the acute effects of excessively foul air at high temperatures are concerned, such, for example, as appeared in the Black Hole at Calcutta, it is probable that they are due to substantially the same causes in man as in animals.

9. The proportion of increase of carbonic acid and of diminution of oxygen, which has been found to exist in badly ventilated churches, schools, theaters, or barracks, is not sufficiently great to satisfactorily account for the great discomfort which such conditions produce in many persons, and there is no evidence to show that such an amount of change in the normal proportion of these gases has any influence upon the increase of disease and death rates which statistical evidence has shown to exist among persons living in crowded and unventilated rooms. The report of the commissioners appointed to inquire into the regulations affecting the sanitary conditions of the British army (1) properly lays great stress on the fact that in civilians at soldiers' ages, in twenty-four large towns, the death rate per 1,000 was 11.9, while in the foot guards it was 20.4 and in the infantry of the line 17.9, and showed that this difference was mainly due to diseases of the lungs occurring in soldiers in crowded and unventilated barracks. These observations have since been repeatedly confirmed by statistics derived from other armies, from prisons, and from the death rates of persons engaged in different occupations, and in all cases tubercular disease of the lungs and pneumonia are the diseases which are most prevalent among persons living and working in unventilated rooms, unless such persons are of the Jewish race. But consumption and pneumonia are caused by specific bacteria, which, for the most part, gain access to the air passages by adhering to particles of dust which are inhaled, and it is probable that the greater liability to these diseases of persons living in crowded and unventilated rooms is to a large extent due to the special liability of such rooms to become infected with the germs of these diseases. It is, however, by no means demonstrated as yet that the only deleterious effect which the air of crowded barracks or tenement-house rooms, or of foul courts and narrow streets, exerts upon

the persons who breathe it is due to the greater number of pathogenic microorganisms in such localities. It is quite possible that such impure atmospheres may affect the vitality and the bactericidal powers of the cells and fluids of the upper air passages with which they come in contact, and may thus predispose to infections, the potential causes of which are almost everywhere present, and especially in the upper air passages and in the alimentary canal of even the healthiest persons, but of this we have as yet no scientific evidence. It is very desirable that researches should be made on this point.

10. The discomfort produced by crowded, ill-ventilated rooms in persons not accustomed to them is not due to the excess of carbonic acid, nor to bacteria, nor, in most cases, to dusts of any kind. The two great causes of such discomfort, though not the only ones, are excessive temperature and unpleasant odors. Such rooms as those referred to are generally overheated, the bodies of the occupants and, at night, the usual means of illumination contributing to this result.

The cause of the unpleasant, musty odor which is perceptible to most persons on passing from the outer air into a crowded, unventilated room is unknown; it may, in part, be due to volatile products of decomposition contained in the expired air of persons having decayed teeth, foul mouths, or certain disorders of the digestive apparatus, and it is due, in part, to volatile fatty acids given off with, or produced from, the excretions of the skin, and from clothing soiled with such excretions. It may produce nausea and other disagreeable sensations in specially susceptible persons, but most men soon become accustomed to it, and cease to notice it, as they will do with regard to the odor of a smoking car, or of a soap factory, after they have been for some time in the place. The direct and indirect effects of odors of various kinds upon the comfort, and perhaps also upon the health, of men are more considerable than would be indicated by any tests now known for determining the nature and quantity of the matters which give rise to them. The remarks of Renk (32, p. 174) upon this point merit consideration. Cases of fainting in crowded rooms usually occur in women, and are connected with defective respiratory action due to tight lacing or other causes.

Other causes of discomfort in rooms heated by furnaces or by steam are excessive dryness of the air, and the presence of small quantities of carbonic oxide, of illuminating gas, or of arsenic derived from the coal used for heating.

11. The results of this investigation, taken in connection with the results of other recent researches summarized in this report, indicate that some of the theories upon which modern systems of ventilation are based are either without foundation or doubtful, and that the problem of securing comfort and health in inhabited rooms requires the consideration of the best methods of preventing or disposing of dusts of various kinds, of properly regulating temperature and moisture,

and of preventing the entrance of poisonous gases like carbonic oxide derived from heating and lighting apparatus, rather than upon simply diluting the air to a certain standard of proportion of carbonic acid present.

It would be very unwise to conclude, from the facts given in this report, that the standards of air supply for the ventilation of inhabited rooms, which standards are now generally accepted by sanitarians as the result of the work of Pettenkofer, De Chaumont, and others, are much too large under any circumstances, or that the differences in health and vigor between those who spend the greater part of their lives in the open air of the country hills, and those who live in the city slums, do not depend in any way upon the differences between the atmospheres of the two localities except as regards the number and character of microorganisms.

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